The International Journal's
Research Journal of Science & IT Management
ISSN:2251-1563

Geochemical Evaluation of Okaba (Odagbo) Coal Deposit, Anambra Basin, Nigeria

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Abstract
Geochemical studies have been carried out on coal samples from Okaba (Odagbo) in the Anambra Basin of Nigeria to determine their geochemical characteristics and possible use as coking coal or otherwise. The geochemical characteristics of a coal determine its usability as a coking coal or as mere steam or non-coking coal. Chemical analysis of the coal samples indicated that, on average, they contain 12.64% moisture, 11.53% ash, 47.56% volatile matter, 0.69% sulphur, 75.41% organic carbon, 5.94% hydrogen, 0.008% sulphate, 0.011% pyrite, 0.23% nitrogen, 10% oxygen and 0.05% phosphorus. Analysis equally showed that the coal has low Free Swelling Index (FSI) of 0.5 and Gray-King coke type of class A. The proximate and ultimate analytical results show that the coal cannot be employed in the steel industry for the generation of substantial heat for the working of the furnace. Hence, the coal deposit in the light of the above characteristics is non-coking and thus cannot be employed in the generation of substantial heat for the working of blast furnace for iron smelting. It can however be employed as a steam coal which can be used as fossil fuel in rail locomotives, steam boat, electricity generation, smokeless briquette and the production of calcium carbide used in the manufacture of acetylene.

Key words: Okaba coal, ultimate analysis, proximate analysis,free swelling index, gray-king coke type

1.**Introduction**. Nigeria's coal reserves are in excess of 1.2 billion tones of proven, indicated and inferred categories, Okaba deposit inclusive (Famuboni, 1996). Despite the above fact, not much of the county's coal has been properly utilized. This may be partly attributed to lack of comprehensive and reliable geo-data about the mineral to guide the prospective user. Prominent among these wanting geo-data is a comprehensive and up-to-date geochemical characteristic of the coals, which are paramount to the choice of any coal deposit for a particular purpose. The above becomes more disturbing especially by the time our dreamed iron and steel industry begins functioning during which much quantity of coking coal is required for the working of the blast furnace.

This research has been undertaken to examine the geochemical parameters of Okaba coal deposit in order to elucidate on its best application for man's use.

The use of most bulk minerals is a function of their physiochemical properties. Coal as a multipurpose bulk mineral offers multiple uses and these uses are dependent on a specific physical and chemical properties exhibited by the mineral. Thus, there is the need for a timely and intensive research and acquisition of detailed Petrological and geochemical data on coals in order to determine the use to which they can be put. General analyses had been carried out on the Nigerian Coals and the results well documented.However, the analyses are so generalized that specific coal deposits are not tied to any specific uses based on the results of the analyses.

The study area covers Okaba (Odagbo) Coal deposit, located about 16km north-east of Ankpa in Kogi State. It extends from the eastern limit of its outcrop at the tributaries of the Okpokwu, Otokpa and Okaba rivers to great depths under younger sediments (Late Maastrichtian-Tertiary) west wards(figure 1).

The area can be accessed through a 10km road off the Ankpa-Makurdi Federal Highway. The road runs via the Okaba and Odagbo communities of Ankpa District.

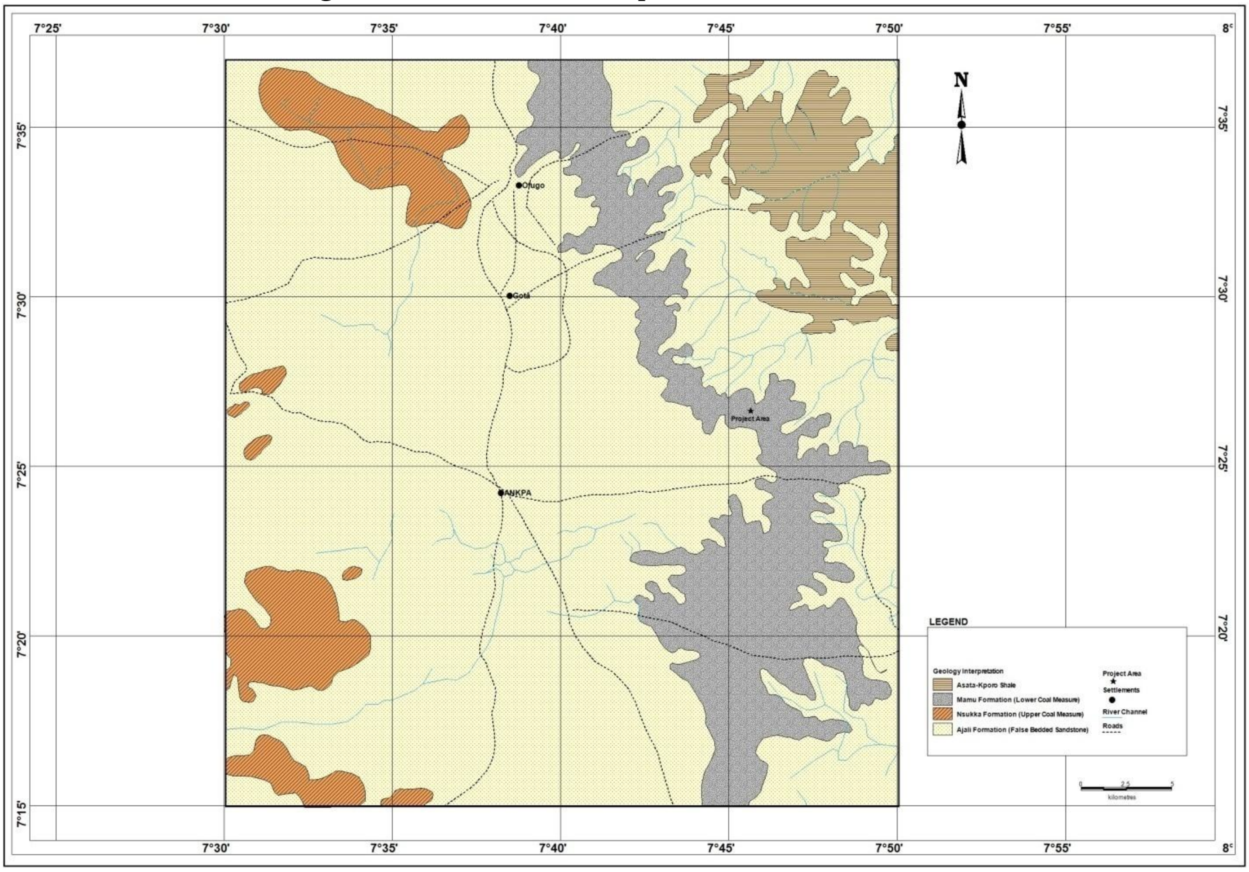

Fig. 1: Location Map of the Project Area

Anambra Basin is located at the southern part of Nigeria and it is sandwiched at the mid-point of the intersection of Bida Basin and Niger Delta

Stratigraphically, Anambra Basin is filled with Campanian-Eocene sediments which are deposited in a stratigraphical sequence, as follows starting from the youngest top stratum to the oldest bottom stratum.These strata are Bende, Imo, Nsukka, Ajali, Mamu, Nkporo and Lafia Formation.

The Bende Formation outcrops as Nanka sands within the Anambra Basin and it basically constitute of large lenticular sands. The sands are characterized by cross bedding, loose; medium to coarse grained and poorly sorted. The formation is dated Eocene.

The Imo Formation overlies the Nsukka Formation and is characterized by carbonaceous shales, sandstones which are medium to coarse grained and some traces of coaly shales. The formation is dated Paleocene.

The is followed by the Nsukka Formation also called Upper Coal Measure because it hosts deposits of the second phase of coal around the area. It consist alternations of sandstones, shales and coal seams. Thin limestone occurs at the top of the sequence. The formation is dated Maastrichtian to Paleocene. It was believed to be deposited under paralic conditions which prevailed during the second post Santonian transgressive cycle (Nwajide, 1989).

Overlying the Mamu Formation is the Ajali Formation, which is also referred to as the false-bedded sandstone. It consists of about 300m coarse grained bedded sandstones and marks the height of regression at a time when the coastline was still concave (Nwajide, 1989). The sandstones are friable, fine to medium grained. The formation was dated Maastrichtian and was regarded as a continental sequence inter-digitating with the paralic Mamu formation.

The Mamu Formation which is also called the Lower Coal Measures consists mainly of sandstones, carbonaceous shales and coal seams. The sandstones are fine to medium grained and yellow in colour. The shales and mudstones are blue or grey. It is known to be up to 400m thick and marks a phase of deltaic-lagoonal environment (Onoduku, 2003). The Mamu Formation occurs as a narrow strip trending north-south from the Calabar flank, swinging west round the Ankpa Plateau and terminating at Idah near the Niger River. The formation is Maastrichtian in age.

The Nkporo Formation consists essentially of clays, blue dark grey shales with occasional thin beds of sandy shale and sandstone. The formation verges on the outside of the Anambra Basin and dips gently to the South-West below the Ajali Formation. The formation was dated lower Maastrichtian.

The Lafia Formation is the youngest formation that was deposited within the Anambra Basin. The formation was described as continental ferruginised sandstones, red, loose sands, flaggy mudstones and clays. The formation have been dated Lower Maastrichtian to Upper Campanian.

2. **Materials and Methods**

The coal samples used for the various geochemical analyses were obtained from Okaba (Odagbo) coal deposit. A total of 10 samples were taken from the run-of-mine, coal seams (in-situ) and mine ponds. The samples were carefully labeled and bagged after some detailed macroscopical examinations were carried out on them and appropriately recorded in a field notebook. The carefully bagged samples were then taken for various geochemical analyses, including proximate and ultimate analyses.

The laboratory analytical work which was carried out at the National Metallurgical Development Company, Jos included the various methods employed in analyzing coal samples for its various components. The variables analyzed included the organic carbon, hydrogen, nitrogen, sulphur, phosphorus and oxygen contents as well as pyrite, all of which constitute the ultimate analysis. The proximate analysis included moisture content, ash content and the volatile matter.

A 1kg weight of each sample of the coal was taken and grounded to pass a 210 micron test sieve and the powdery coal used for various analyses. The methods followed in these analyses were adopted from Afonja (1994).

2.1 **Carbon and Hydrogen Determination**. A 1gm sample taken from the coal ground to pass a 0.2mm test sieve was burnt in a three-stage Lieberg furnace in a current of oxygen. The carbon dioxide and water formed were absorbed by soda asbestos and magnesium per chlorate respectively, and determined gravimetrically to ascertain the level of carbon and hydrogen contents. The analyses show that the Okaba coal contains an average of 75.41% carbon and 5.94% hydrogen.

2.2 **Moisture Determination**. The moisture content was determined by drying a 1gm coal sample in a minimum free space oven at 110^{o}C for four hours in an atmosphere of nitrogen. The sample was then cooled in a desicator in an atmosphere of nitrogen and weighed. This process was repeated until a consistent weight of the coal sample was achieved. The difference in the original weight of the coal sample and the weight of the dry coal sample gave the weight of the moisture content and usually expressed in percentage. The analysis showed that the coal contained an average of 12.64% moisture content.

2.3 **Ash Content Determination**. The ash content was determined by incinerating a 1gm coal sample in a special furnace at 815^{o}C, the heatingprogram being in accordance with BS 1016 Part 3 specifications. The sample was then cooled in a desicator, weighed and re-incinerated until the weight became consistent. The difference in the initial weight and the final weight of the coal sample gave the ash content. The determination shows the coal to contain an average of 11.53% ash.

2.4 **Determination of Volatile Matter**. 1gm of the crushed coal sample was heated in minimum air at 900^{o}C for seven (7) minutes. The heated sample was then cooled in a desicator and weighed. This process was repeated until a consistent weight of the sample was achieved. The average volatile matter determined for the coal was 47.56%.

2.5 **Sulphur Determination**. The sulphur content was determined by mixing a 1gm sample of coal of 0.2mm particle size with Eschka mixture and heated until all the sulphur was converted to sulphate. The resultant sulphate solution was then extracted and determined gravimetrically by precipitation with barium chloride. Eschka mixture refers to a mixture of either K_2CO_3 or Na_2CO_3 and magnesia but in this study Na_2CO_3 (sodium carbonate) was used. The nature of the sulphur analyzed in the coal was determined by boiling a 5gm sample of coal with dilute hydrochloric acid to bring the sulphate sulphur and non-pyritic iron into solution and filtered. The filtrate was then made alkaline to precipitate the non-pyritic iron which was then removed by filtration. The sulphate sulphur was precipitated from the filtrate as barium sulphate and determined gravimetrically. The difference between the total sulphur and sum of the pyretic sulphur and sulphate sulphur was computed as the organic sulphur. This is illustrated in the formula: $S_{org} = S_{total} – (S_{sulphate} + S_{pyrite})$. The analysis showed that the coal contains on average basis, 0.69% total sulphur, 0.67% organic sulphur, 0.008% sulphate sulphur and 0.013% pyretic sulphur.

2.6 **Determination of Free Swelling Index (FSI).** To determine the FSI, a 1gm finely crushed sample of the coal was placed in a crucible without appreciable packaging, and heated under carefully controlled conditions of temperature and pressure. This made the coal to soften and the particles fused. The coal mass then swell and re-solidified to resemble a very porous mass of coke, which is light and much larger in volume than the original coal sample. The swelling index was then analyzed by simply comparing the shape of the residue of the swollen coal with a series of standard samples provided in the laboratory. The FSI of Okaba coal was found to be 0.5.

2.7 **Gray-King Coke Type Test**. A 20gm of the finely crushed coal sample was heated in a silica tube at a rate of 5^oC/min between 300 - 600^oC. The resultant coal residue was compared with series of reference cokes provided in the analytical laboratory. The analysis showed the Okaba coal to be the Gray-King coke type ‘A’.

2.8 **Phosphorus Determination**. Phosphorus was determined by treating 1gm of the coal ash with a hot mixture of HNO_3, H_2SO_4 and HF acids. This volatilized the silica and dissolved the phosphorus to precipitate a complex phospho-molybdate from which the phosphorus content was estimated. The phosphorus content of the Okaba coal was found to be 0.02% on average.

2.9 **Oxygen Determination**. The finely crushed coal was pyrolized at 1200^oC in a current of nitrogen and the resultant gases passed over activated carbon at 200^oC. This converted the oxygenated products into CO which was then oxidized to CO_2 by reacting with O_2. The oxygen content was then determined using classical method. The analysis showed that the Okaba coal contained an average of 10% oxygen.

3. **Results and Discussion**

3.1 **Properties of Okaba Coal**. Okaba coal in hand specimen is light, partly massive, hard, dull-black to grayish black. It possesses perfect basal cleavage, concoidal fracture and shows elements of brittleness. Other striking features of Okaba coal are low free swelling index, high moisture content, moderate to high ash content, moderate volatile matters and high fixed carbon content. The high carbon content is an indication of the maturation of the coal and its anticipated high caloric value. It is of Gray-King coke type A, which implies that its carbonization products are usually in powder form but may contain some pieces, which however cannot be handled without breaking. This implies that the coal is non-coking and thus cannot produce a good coke.

Table 1: Proximate Analysis Result of Okaba Coal

Parameters/ sample nos	OK1	OK2	OK3	OK4	OK5	OK6	OK7	OK8	OK9	OK10	AVERAGE
% Moisture	10.8	9.4	14	10	16	14.6	11.4	12	12.6	16.2	12.64
% Ash	11	11.6	9.8	11.6	15.86	13.4	10.8	11	9.6	11.64	11.53
% Volatile Matter	46	44.7	51.9	46	43.9	44.2	54	50.9	47	48	47.56

Table 2: Ultimate Analysis Result of Okaba Coal

PARAMETERS/ SAMPLE Nos	OK1	OK2	OK3	OK4	OK5	OK6	PK7	OK8	OK9	OK10	AVERAGE
% Carbon(DAF)	78	73.9	75.0	76.0	77.0	74.8	77.4	74.0	74.0	74.0	75.41
% Hydrogen (DAF)	6	4.6	5.8	4.9	6.2	7.0	6.8	6	6	6.1	5.94
% Sulphate Sulphur(DAF)	0.01	0.02	nd	nd	nd	0.01	0.01	0.02	nd	0.01	0.008

% Pyritic Sulphur(DAF)	0.02	0.02	nd	0.01	0.01	nd	0.03	0.02	0.02	nd	0.013
% Total Sulphur	1	0.05	1	1.21	0.70	1	nd	0.5	0.5	0.5	0.69
% Nitrogen(DAF)	1	nd	0.7	nd	nd	nd	0.2	0.3	0.1	nd	0.23
% Oxygen(DAF)	11	9	7.8	8.6	11	11	10.6	10.6	9.9	10.8	10
% Phosphorous(DAF)	0.0	0.0	0.01	nd	nd	nd	nd	nd	nd	nd	0.05
FSI	0.5	0	0.5	0	0	0	0	0	0	0	0
Gray-King Coal Type	A										
%Organic Sulphur	0.97	0.46	1	1.2	0.69	0.99	nd	0.46	0.48	0.49	0.67

3.2 **Effect of Ash Content**. High ash content in coals give rises to a high slag volume and low blast furnace efficiency. High ash also results in high coke rate, which is a consequence of accelerated oxidation of coke by carbon dioxide and oxygen due to the catalytic activities of the metallic oxides in the ash. The high ash content is also an indication of low degree of coalification.
The Okaba coal contains a relatively moderate to high ash (11.53%) as compared to the low ash value required for prime coking coals. Some imported coking coals (e.g. Bellview and Agro-Allied), which are to be blended with some Nigerian coals (e.g. Enugu and Lafia-Obi) for their cokability enhancement, contain 6.13% and 9.62% ash respectively (Wessiepe, 1992). This puts Okaba coal at a disadvantage in terms of usage as a coking coal even on blending with some other coking coal since ash content is undesirable as far as coal utilization is concerned. The lower the ash content of a coal, the better is it application as a source of fossil fuel especially in the steel industry (Wessiepe, 1992). However, coking coal with ash content up to 20% are being used for smelting iron in some parts of the world (Afonja, 1974). In such cases, coke and flux consumption per ton of pig iron produced is relatively high. It is possible and advisable that the ash content of Okaba coal be reduced considerably by washing.

3.3 **Effect of Sulphur Content**. The sulphur content of Okaba coal is relatively low (average value of 0.691%). This puts the coal at an advantage in this regard both in terms of usage as a fossil fuel and environmental consideration. High sulphur contents is undesirable in steel and coking coal because it promotes the formation of insoluble iron sulphides during iron making causing brittleness of the iron produced. The formation of di- and tri- sulphur oxide during coal carbonization which gives rise to sulphuric acid that causes industrial fumes will be highly minimal due to the low content of sulphur in the coal. The sulphur is mostly present in the organic form. While pyretic sulphur content of a coal can be reduced considerably by leaching, organic and sulphate sulphur are very difficult to remove.

3.4 **Effect of Moisture Content**. The Okaba coal contains an average of 12.64% moisture and this is considered to be too high for a coking coal. The high moisture content is an indication that the coal is of low rank, possibly the rank of sub-bituminous grade. It can also be inferred that the coal has not sufficiently experience deep burial to warrant enough transformation at the phase of catagenesis during which an appreciable part of the moisture would have been lost. In terms of usage, the coal may not be suitable for high-energy generation or the blast furnace due to its high moisture content. When compared with some imported coking coal e.g. Bellview and Agro-Allied coals, its moisture value is very high. Bellview has a moisture content of 0.58% while Agro-Allied has 1.62% and both coals are good coking coals intended to be blended with Enugu and Lafia-Obi coals, to enhance their cokability (Adebayo, 2002 – Personal Communication).

3.5 **Volatile Matter**. Okaba coal has an average of 47.56% volatile matter which is too high and is an indication that the coal is relatively young and will likely not have any appreciable coking characteristics. Coking coals normally have a volatile matter content of between 20 and 32 percent (Afonja, 1974).

Volatile matters are components of coal that are lost in the form of gases and vapour on carbonization. These include hydrogen, oxygen, nitrogen, sulphur, phosphorus and carbon. the percentage of the volatile matter given off by a coal on carbonization is directly related to the amount of the above mentioned elements contained in a coal.
The elements that constitute the volatile matters are given off in the form of HO_2, CO, CHO_4, and NO2 etc. High volatile matter means high contents of these elements and is an indication of low rank of the coal. This in turn is an indication of the coking property of a coal.

3.6 **Implication of the Ultimate Analysis**. This is second in rank to proximate analysis as far as coal analysis is concerned. The average carbon content of the Okaba coal was found to be 75.41% and this was considered low. This is an indication that the Okaba coal is relatively young and of the sub-bituminous rank.
The swelling index, Gray-King coke type results show that Okaba coal has very low agglomerating characteristics. In fact the coke produced from the Okaba coal crumbled into powder on handling. A coal that does not swell, softens or become fluid on heating will almost certainly not form a coherent coke.
Furthermore, the hydrogen content of the coal (average value of 5.49%) is considered too low while that of oxygen (10.0%) was considered too high and they are indication that the coal is relatively young and still undergoing maturation. The nitrogen and phosphorus contents are relatively low (0.23% and 0.02% respectively). This places the coal at an advantage in terms of usage either as coking or non-coking coal since the environment will be less polluted as consequence of burning the coal.

3.7 **Possible Uses of Okaba Coal**. Based on the analyzed properties of the coal, it is not suitable for coking coal. The coal can however be used as fossils fuels in rail locomotives, steam boat and for electric generation.
The coal can equally be processed to smokeless briquette for domestic purposes e.g. home warming, cooking, etc. This will reduce the desertification problem caused by deforestation by firewood sourcing. The use of smokeless coal briquette is highly recommended for Nigeria especially the northern part where the problem of deforestation is alarming. It can also be used in the production of calcium carbide a raw material for the manufacture of acetylene.

4. **Conclusion**. The study has shown that Okaba coal, in the light of the analyzed geochemical parameters, is a high volatile, moderate to high ash, sub-bituminous non-coking coal. Consequently, the coal may not be suitable for use as a coking coal. The coal can however find applications in industrial uses such as dye industry, chemical industries etc.

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